BROOKHAVEN NATIONAL LABORATORY

Superconducting

Magnet Division

LHC Phase 1 Upgrade
Beam Separation Dipoles

June 20, 2008

Michael Anerella

Outline

- Overview
- Anticipated Changes
- Tooling and Equipment
- Schedule Discussion
- Early Cost Comments
- Conclusions

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Overview

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Scope:

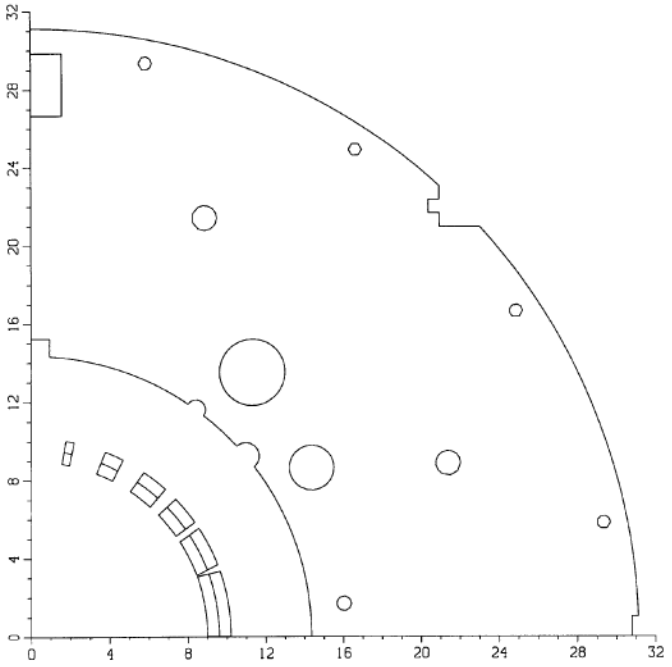
- Design / Build / Test / Ship (10) cold masses in 5 cryostats

Design Basis: RHIC DX Dipole

- 18cm aperture Cosθ NbTi, 4.3T @4.6K
- 1 layer coil, 71 turns, 11.68mm 36 strand cable
- 641mm O.D., 3.7M magnetic length

History:

- 12 units operating reliably in RHIC for ~ 9 years
- Most difficult magnet in RHIC:
  - 200 mPa coil azimuthal preload
  - 440 kN axial coil preload



Anticipated Changes - coil

Coil Ends

- Large radius, constant perimeter conductor path – significant angle from vertical
- Large grouped spacers between turns
- Large preload due to high axial Lorentz forces
  →supplemental support required

→Opportunity for improvement for LHC:

→Greater quantity of thinner spacers for better composite structure

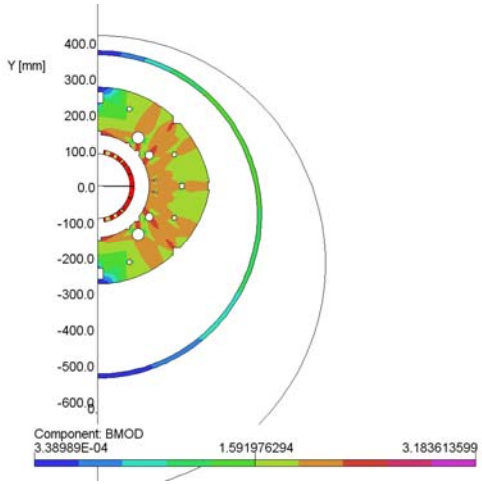
→Reduce conductor angle from vertical

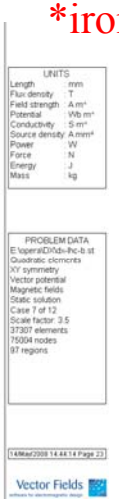
Yoke Options for LHC D1 from RHIC DX (courtesy R. Gupta)

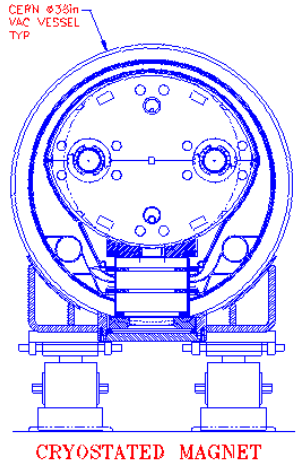
Note : Oblate yoke has ~ 0.7 mT fringe field outside cryostat in 2-D* and ~2 T in yoke at midplane.
Sextupole saturation is ~3 unit at 2/3 radius.

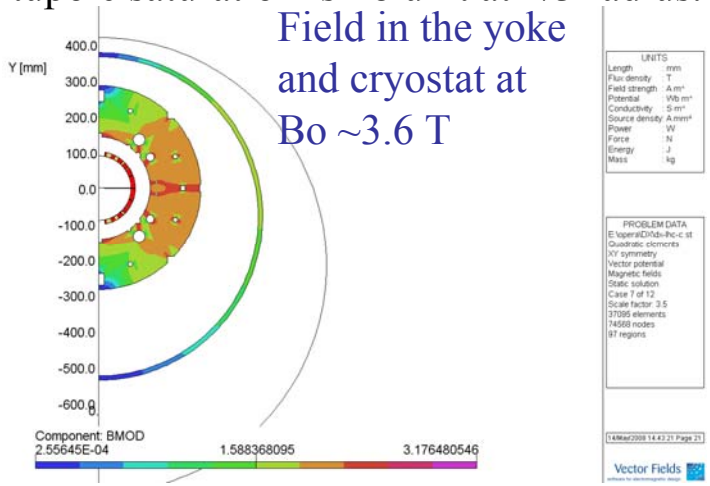
Note : Circular yoke has ~ 6.5 mT fringe field outside cryostat in 2-D* and ~2.4 T in yoke at midplane.
Sextupole saturation is ~8 unit at 2/3 radius.

*iron is removed in coil ends

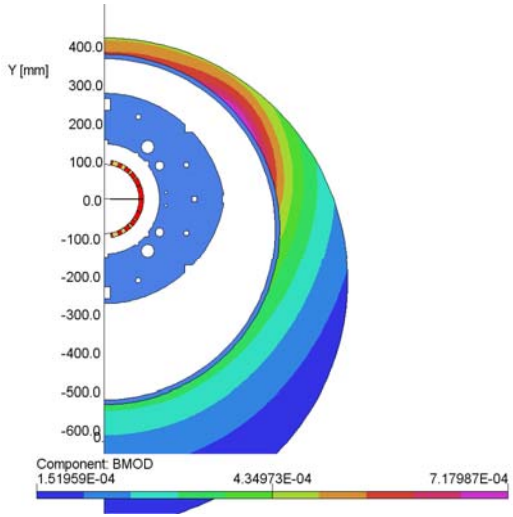


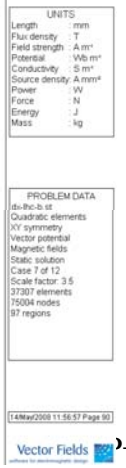




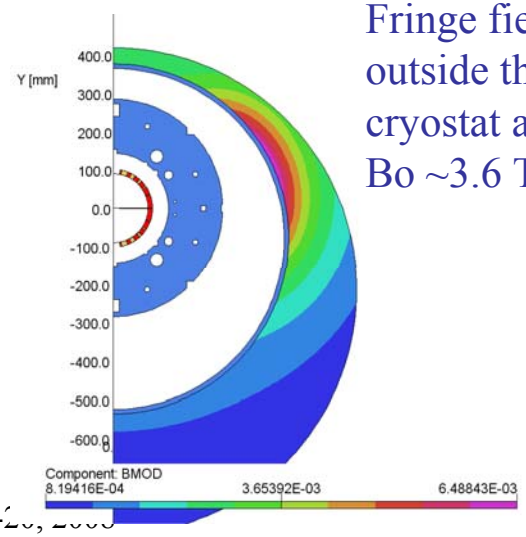


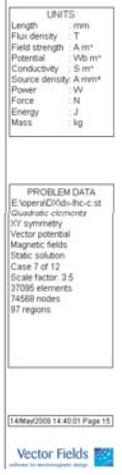
Field in the yoke and cryostat at Bo ~3.6 T





BNL 2-in-1 dipole in standard LHC Cryostat





Fringe field outside the cryostat at Bo ~3.6 T

Anticipated Changes – Cold Mass

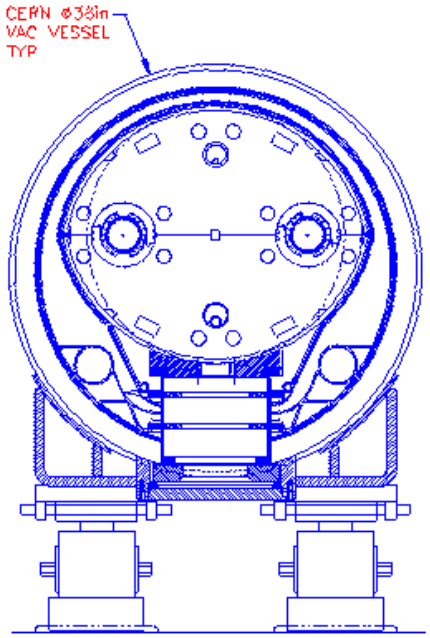
Reduce Yoke O.D.to fit LHC cryostat

"Cascade" effects:

- shell diameter
- end plate diameter (thickness?)
- end volume diameter

Cold Mass Interface elements:

- helium supply, exiting current leads as needed
- Support cradles to match LHC posts



Anticipated Changes – Magnet

2 Cold Masses in 1 Cryostat

Probable (Possible?) Configuration:

- Standard LHC heat shield
- Standard LHC crysotat (except length - diameter, legs, survey monuments, etc.)
- 4 standard LHC support posts (2 per cold mass)
- Leads pointed toward center (for common power, elimination of bus, etc.)
- Centrally located IFS lines, helium supply, etc.
- "Non-weight bearing" axial anchor between cold masses (limits thermal contraction effects on power leads, helium lines)

Not Anticipated – Planned

- Warm to Cold transitions at magnet ends
- Warm bore tubes
- Quench protection (other than internal quench resistors)

Tooling Status

- All tooling completely proven during production
- Some tools idle since
- Some tools reconfigured for other programs & need reconversion (collaring press, etc.)
- Some tools require remediation, eg.:
  - Curing press – oil leak in heat exchanger
  - Winding machine – obsolete computer system

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Available Equipment 1

Cable Insulating Line

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Available Equipment 2

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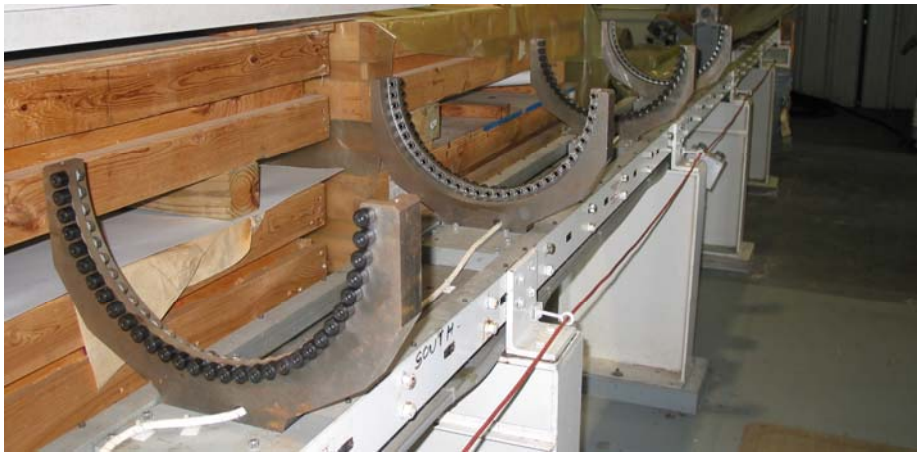
7M Winding Machine

18cm Coil Winding Carriage, Roller Supports & Rotating Drive

18cm Coil Winding Mandrel Supports



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Available Equipment 3

Coil Curing formblock

Coil mandrel

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Available Equipment 4

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curing press

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Available Equipment 5

Collaring Press

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Available Equipment 6

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Lifting Devices

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Available Equipment 7

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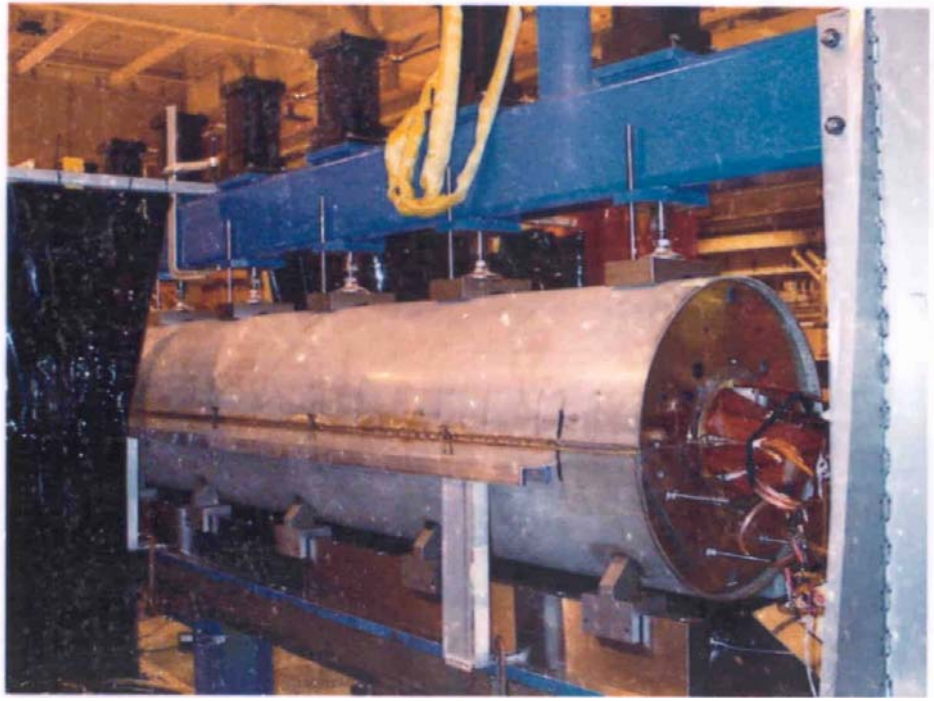
Yoke Assembly / Shell Welding Fixture



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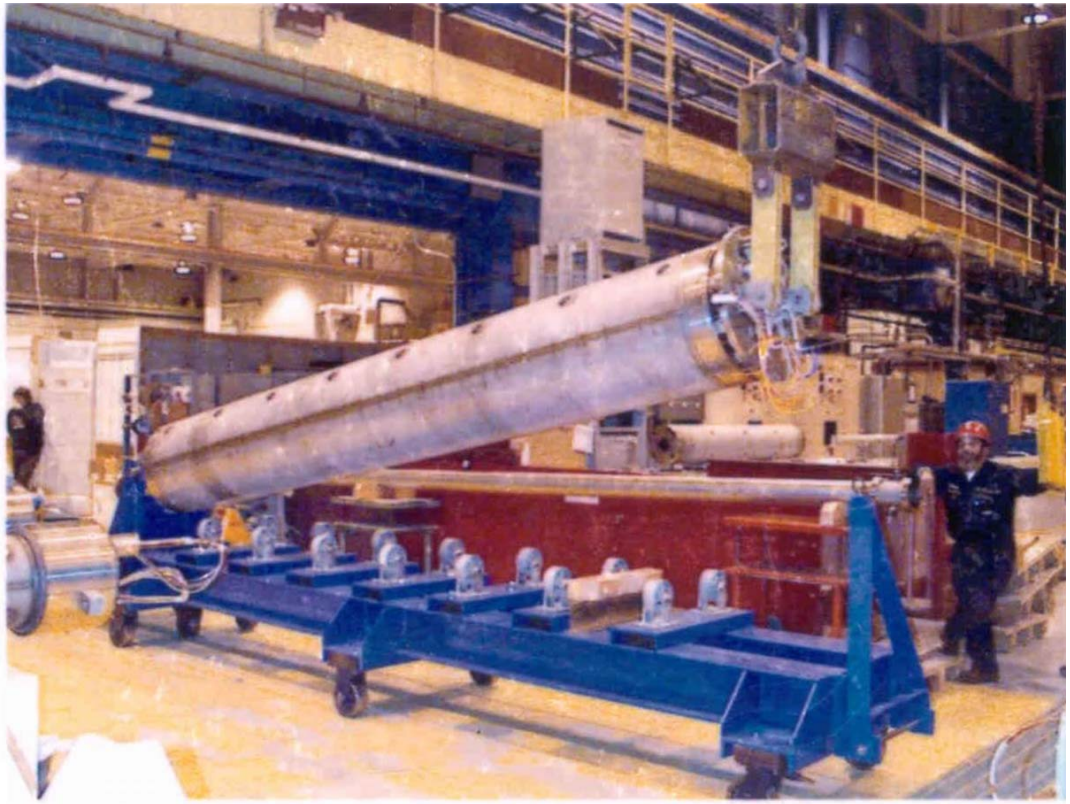
Available Equipment 8

Uprighting Fixture



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Available Equipment 9

6.1M Vertical Test Dewar

Dewar I.D. = 700mm

Crane Hook max. height = 7.6M

Dewar height above floor = 0.9M

(max. coil length ~ 6M)

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Available Equipment 10

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Cold Mass Insertion into Cryostat

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Available Equipment 11

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Shipping Container, Shipping Restraints

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Schedule Highlights

FY10:

- Design Mods
  - Coil ends
  - Interfaces: Cradles, Helium ports, etc.
  - Cryostat Assembly
- Procurement: SC, Coil Parts, Cold Mass Parts (30%)
- Re-commission tools
- Complete Test Coils
- Start Cold Mass #1

Schedule Highlights (cont'd)

FY11:

- Procurement: Cold Mass Parts (70%)
- Complete CM #1 Assembly & Cold Test
  - →Wait for test before starting CM #2 Coils
- Complete Coil Fabrication
- Assemble, Test CM #2 through CM #8
- Assemble and Ship Magnet #1 and Magnet #2

Schedule Highlights (cont'd)

FY12:

- Assemble, Test CM #9 and CM #10
- Assemble and Ship Magnets #3, #4 and #5

→ Last Delivery at CERN ~ April 2012

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Schedule I

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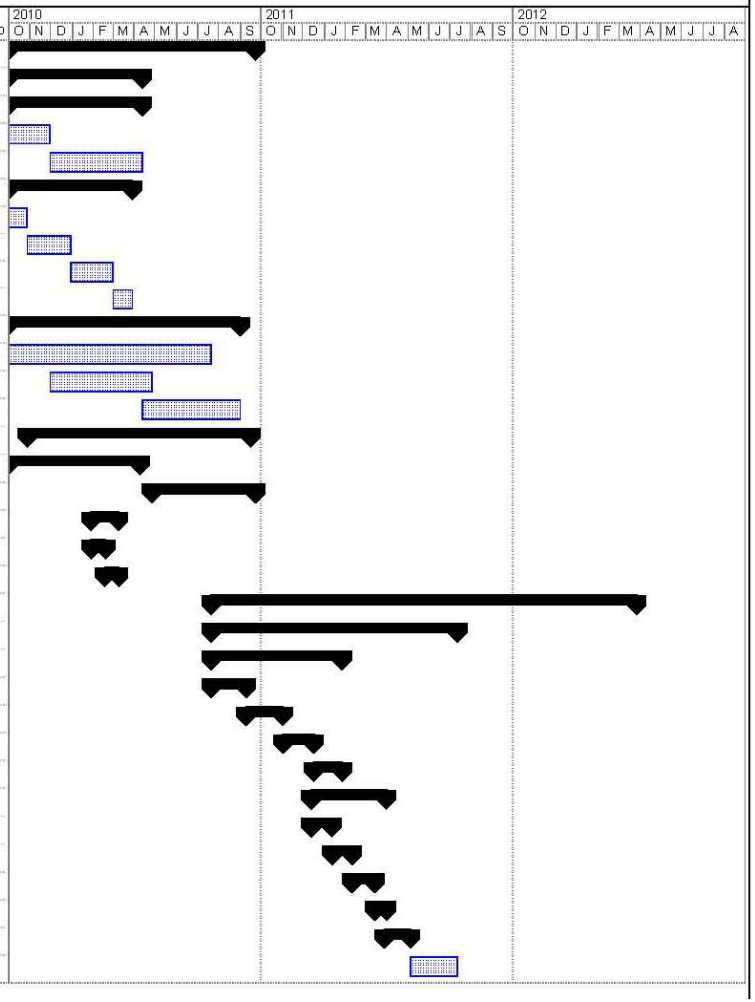
Construction Project

ID	Task Name	Duration	Start	Finish	Predecesso
1	**Magnet and Magnet Tooling**	**245 days**	**Thu 10/1/09**	**Thu 9/23/10**	
2	**Engineering / Design**	**130 days**	**Thu 10/1/09**	**Mon 4/12/10**	
3	**Production Magnet**	**130 days**	**Thu 10/1/09**	**Mon 4/12/10**	
4	**Coil Assembly Upgrades**	**40 days**	**Thu 10/1/09**	**Mon 11/30/09**	
5	**Magnet Assembly**	**90 days**	**Tue 12/1/09**	**Mon 4/12/10**	4
6	**Magnet Tooling**	**120 days**	**Thu 10/1/09**	**Mon 3/29/10**	
7	Transport fixture	20 days	Thu 10/1/09	Wed 10/28/09	
8	Insertion Fixture mods	40 days	Thu 10/29/09	Wed 12/30/09	7
9	Interconnect Fixtures	40 days	Thu 12/31/09	Mon 3/1/10	8
10	Shipping Restraint Mods	20 days	Tue 3/2/10	Mon 3/29/10	9
11	**Parts Fab / Procurement**	**230 days**	**Thu 10/1/09**	**Wed 9/1/10**	
12	**Superconductor**	**200 days**	**Thu 10/1/09**	**Wed 7/21/10**	
13	**Coil Parts**	**100 days**	**Tue 12/1/09**	**Mon 4/26/10**	4
14	**Cold Mass Parts**	**100 days**	**Tue 4/13/10**	**Wed 9/1/10**	5
15	**Tool Fab**	**220 days**	**Thu 10/29/09**	**Thu 9/16/10**	
20	**Re-commission Tools**	**129 days**	**Thu 10/1/09**	**Fri 4/9/10**	
45	**Install New Tools**	**105 days**	**Tue 4/27/10**	**Thu 9/23/10**	
50	**Long Test Coils (2)**	**27 days**	**Fri 1/29/10**	**Tue 3/9/10**	
51	**copper practice coil #1**	**15 days**	**Fri 1/29/10**	**Thu 2/18/10**	
61	**NbTi practice coil #1**	**13 days**	**Thu 2/18/10**	**Tue 3/9/10**	
71	**Magnet Assembly**	**418.5 days**	**Thu 7/22/10**	**Wed 3/28/12**	
72	**Magnet #1**	**242.5 days**	**Thu 7/22/10**	**Wed 7/13/11**	
73	**Cold Mass #1**	**127.5 days**	**Thu 7/22/10**	**Thu 1/27/11**	
74	**Coils**	**35.5 days**	**Thu 7/22/10**	**Fri 9/10/10**	12
105	**Cold Mass Assembly I**	**37 days**	**Fri 9/10/10**	**Tue 11/2/10**	
112	**Install, Cold Test**	**29 days**	**Tue 11/2/10**	**Fri 12/17/10**	
120	**Cold Mass Assembly II**	**26 days**	**Fri 12/17/10**	**Thu 1/27/11**	
124	**Cold Mass #2**	**75 days**	**Mon 12/13/10**	**Fri 4/1/11**	
125	**Coils**	**20 days**	**Mon 12/13/10**	**Wed 1/12/11**	
146	**Cold Mass Assembly I**	**20 days**	**Wed 1/12/11**	**Thu 2/10/11**	
153	**Cold Test**	**22 days**	**Thu 2/10/11**	**Tue 3/15/11**	
161	**Cold Mass Assembly II**	**13 days**	**Tue 3/15/11**	**Fri 4/1/11**	
165	**Magnet Assembly**	**28 days**	**Tue 3/29/11**	**Fri 5/6/11**	
177	Ship	45 days	Fri 5/6/11	Wed 7/13/11	176



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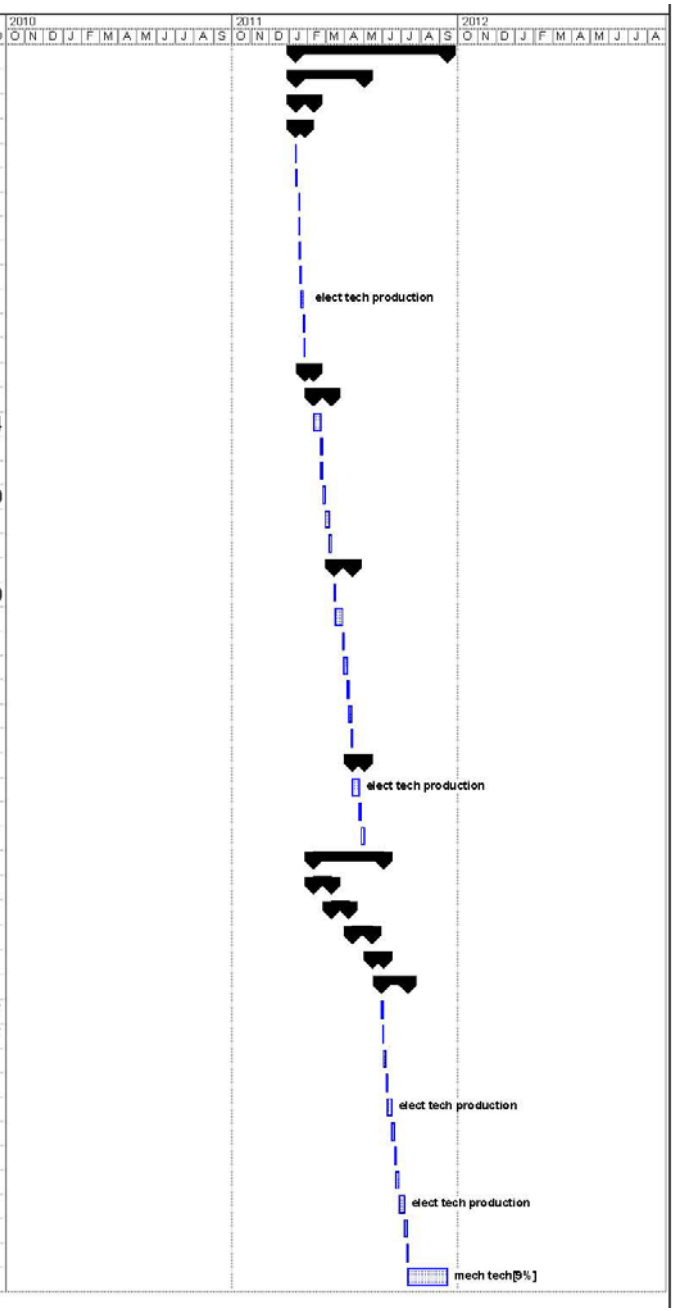
Schedule II

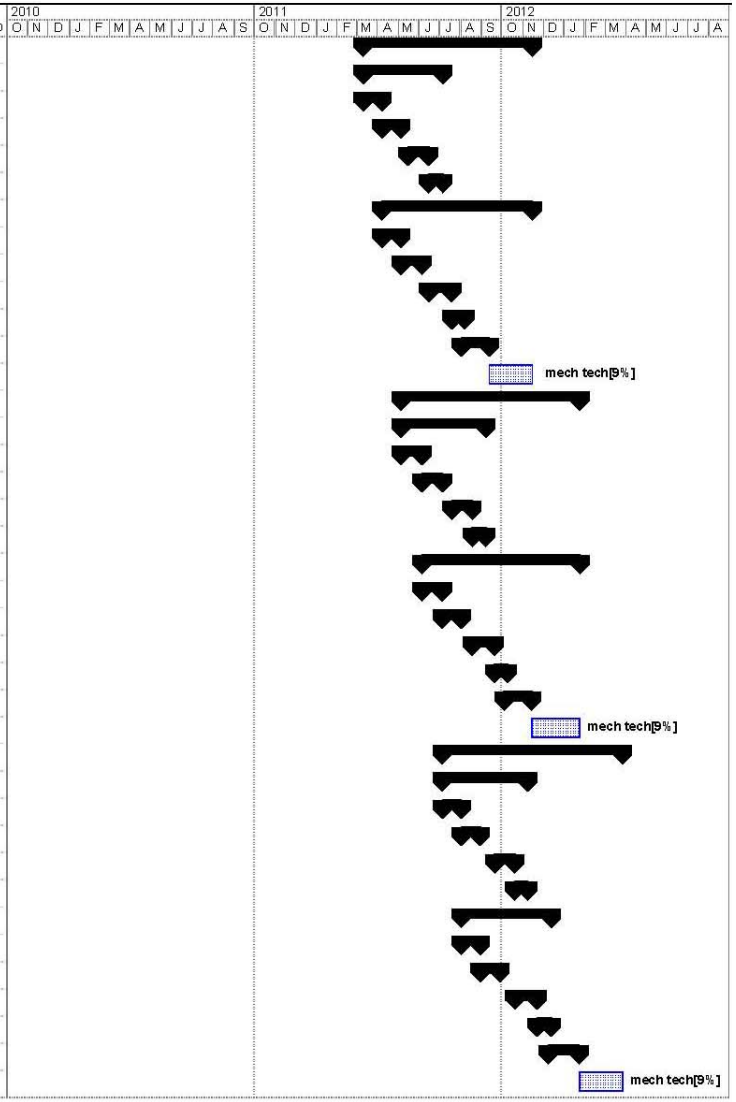
ID	Task Name	Duration	Start	Finish	Predecesso
178	**Magnet #2**	**169 days**	**Wed 1/12/11**	**Wed 9/14/11**	
179	**Cold Mass #3**	**77 days**	**Wed 1/12/11**	**Tue 5/3/11**	
180	**Coils**	**20 days**	**Wed 1/12/11**	**Thu 2/10/11**	
181	**coil #1**	**10 days**	**Wed 1/12/11**	**Thu 1/27/11**	
182	install mandrel on winder	0.5 days	Wed 1/12/11	Wed 1/12/11	145
183	wind coil	2 days	Thu 1/13/11	Fri 1/14/11	182
184	install pushers, liners	0.5 days	Tue 1/18/11	Tue 1/18/11	183
185	move to cure sta. & install in FB	0.5 days	Tue 1/18/11	Tue 1/18/11	184
186	cure	1 day	Wed 1/19/11	Wed 1/19/11	185
187	remove from FB & move to test	1 day	Thu 1/20/11	Thu 1/20/11	186
188	measure, test	2 days	Fri 1/21/11	Mon 1/24/11	187
189	splice, stabilize leads	2 days	Tue 1/25/11	Wed 1/26/11	188
190	transport to Bldg 902	0.5 days	Thu 1/27/11	Thu 1/27/11	189
191	**coil #2**	**10 days**	**Thu 1/27/11**	**Thu 2/10/11**	
201	**Cold Mass Assembly I**	**20 days**	**Thu 2/10/11**	**Fri 3/11/11**	
202	assemble coils into collars	7 days	Thu 2/10/11	Tue 2/22/11	200,14
203	collar coils	3 days	Tue 2/22/11	Fri 2/25/11	202
204	assemble yoke	2 days	Tue 2/22/11	Thu 2/24/11	202
205	install coils into yoke	2 days	Fri 2/25/11	Tue 3/1/11	204,20
206	install shells	4 days	Tue 3/1/11	Mon 3/7/11	205
207	install end plates / apply axial load	4 days	Mon 3/7/11	Fri 3/11/11	206
208	**Cold Test**	**22 days**	**Tue 3/15/11**	**Thu 4/14/11**	
209	install in horizontal dewar	2 days	Tue 3/15/11	Thu 3/17/11	160,20
210	connect leads, plumbing	8 days	Thu 3/17/11	Tue 3/29/11	209
211	warm magnetic measurements	2 days	Tue 3/29/11	Thu 3/31/11	210
212	cool down	3 days	Thu 3/31/11	Tue 4/5/11	211
213	test	3 days	Tue 4/5/11	Fri 4/8/11	212
214	warmup	2 days	Fri 4/8/11	Tue 4/12/11	213
215	remove from dewar	2 days	Tue 4/12/11	Thu 4/14/11	214
216	**Cold Mass Assembly II**	**13 days**	**Thu 4/14/11**	**Tue 5/3/11**	
217	wire coils	7 days	Thu 4/14/11	Mon 4/25/11	215
218	complete helium vessel	3 days	Mon 4/25/11	Thu 4/28/11	217
219	pressure / leak test	3 days	Thu 4/28/11	Tue 5/3/11	218
220	**Cold Mass #4**	**79 days**	**Thu 2/10/11**	**Fri 6/3/11**	
221	**Coils**	**20 days**	**Thu 2/10/11**	**Fri 3/11/11**	
242	**Cold Mass Assembly I**	**20 days**	**Fri 3/11/11**	**Fri 4/8/11**	
249	**Cold Test**	**22 days**	**Thu 4/14/11**	**Mon 5/16/11**	
257	**Cold Mass Assembly II**	**13 days**	**Mon 5/16/11**	**Fri 6/3/11**	
261	**Magnet Assembly**	**28 days**	**Tue 5/31/11**	**Tue 7/12/11**	
262	prepare heat shield	2 days	Tue 5/31/11	Thu 6/2/11	263SF
263	measure / install posts	1 day	Thu 6/2/11	Fri 6/3/11	264SF
264	insulate cold masses	2 days	Fri 6/3/11	Tue 6/7/11	260
265	install CM onto heat posts, heat shield	2 days	Tue 6/7/11	Thu 6/9/11	264
266	assemble interconnects	5 days	Thu 6/9/11	Thu 6/16/11	265
267	weld upper shield	3 days	Thu 6/16/11	Tue 6/21/11	266
268	install blankets	2 days	Tue 6/21/11	Thu 6/23/11	267
269	install into cryostat	3 days	Thu 6/23/11	Tue 6/28/11	268
270	install instrumentation lines	5 days	Tue 6/28/11	Thu 7/7/11	269
271	pressure / leak check	2 days	Thu 7/7/11	Mon 7/11/11	270
272	survey	1 day	Mon 7/11/11	Tue 7/12/11	271
273	Ship	45 days	Tue 7/12/11	Wed 9/14/11	272



Schedule III

Construction Project

ID	Task Name	Duration	Start	Finish	Predecesso
274	**Magnet #3**	**173 days**	**Fri 3/11/11**	**Wed 11/16/11**	
275	**Cold Mass #5**	**81 days**	**Fri 3/11/11**	**Thu 7/7/11**	
276	**Coils**	**20 days**	**Fri 3/11/11**	**Fri 4/8/11**	
297	**Cold Mass Assembly I**	**20 days**	**Fri 4/8/11**	**Fri 5/6/11**	
304	**Cold Test**	**22 days**	**Mon 5/16/11**	**Thu 6/16/11**	
312	**Cold Mass Assembly II**	**13 days**	**Thu 6/16/11**	**Thu 7/7/11**	
316	**Cold Mass #6**	**153 days**	**Fri 4/8/11**	**Wed 11/16/11**	
317	**Coils**	**20 days**	**Fri 4/8/11**	**Fri 5/6/11**	
338	**Cold Mass Assembly I**	**20 days**	**Fri 5/6/11**	**Mon 6/6/11**	
345	**Cold Test**	**22 days**	**Thu 6/16/11**	**Wed 7/20/11**	
353	**Cold Mass Assembly II**	**13 days**	**Wed 7/20/11**	**Mon 8/8/11**	
357	**Magnet Assembly**	**28 days**	**Wed 8/3/11**	**Tue 9/13/11**	
369	Ship	45 days	Tue 9/13/11	Wed 11/16/11	368
370	**Magnet #4**	**177 days**	**Fri 5/6/11**	**Wed 1/25/12**	
371	**Cold Mass #7**	**85 days**	**Fri 5/6/11**	**Thu 9/8/11**	
372	**Coils**	**20 days**	**Fri 5/6/11**	**Mon 6/6/11**	
393	**Cold Mass Assembly I**	**20 days**	**Mon 6/6/11**	**Wed 7/6/11**	
400	**Cold Test**	**22 days**	**Wed 7/20/11**	**Fri 8/19/11**	
408	**Cold Mass Assembly II**	**13 days**	**Fri 8/19/11**	**Thu 9/8/11**	
412	**Cold Mass #8**	**157 days**	**Mon 6/6/11**	**Wed 1/25/12**	
413	**Coils**	**20 days**	**Mon 6/6/11**	**Wed 7/6/11**	
434	**Cold Mass Assembly I**	**20 days**	**Wed 7/6/11**	**Wed 8/3/11**	
441	**Cold Test**	**22 days**	**Fri 8/19/11**	**Wed 9/21/11**	
449	**Cold Mass Assembly II**	**13 days**	**Wed 9/21/11**	**Mon 10/10/11**	
453	**Magnet Assembly**	**28 days**	**Wed 10/5/11**	**Tue 11/15/11**	
465	Ship	45 days	Tue 11/15/11	Wed 1/25/12	464
466	**Magnet #5**	**181 days**	**Wed 7/6/11**	**Wed 3/28/12**	
467	**Cold Mass #9**	**89 days**	**Wed 7/6/11**	**Wed 11/9/11**	
468	**Coils**	**20 days**	**Wed 7/6/11**	**Wed 8/3/11**	
489	**Cold Mass Assembly I**	**20 days**	**Wed 8/3/11**	**Wed 8/31/11**	
496	**Cold Test**	**22 days**	**Wed 9/21/11**	**Fri 10/21/11**	
504	**Cold Mass Assembly II**	**13 days**	**Fri 10/21/11**	**Wed 11/9/11**	
508	**Cold Mass #10**	**91 days**	**Wed 8/3/11**	**Wed 12/14/11**	
509	**Coils**	**20 days**	**Wed 8/3/11**	**Wed 8/31/11**	
530	**Cold Mass Assembly I**	**20 days**	**Wed 8/31/11**	**Thu 9/29/11**	
537	**Cold Test**	**22 days**	**Fri 10/21/11**	**Wed 11/23/11**	
545	**Cold Mass Assembly II**	**13 days**	**Wed 11/23/11**	**Wed 12/14/11**	
549	**Magnet Assembly**	**28 days**	**Fri 12/9/11**	**Tue 1/24/12**	
561	Ship	45 days	Tue 1/24/12	Wed 3/28/12	560



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Preliminary Cost Estimate

Superconducting

Magnet Division

Based on:

- "bottoms-up" based on DX actual, LHC actual prices, etc.
- Escalation included @ 3% per FY.
- Detailed labor plan based on available equipment, manpower, current rates w/ esc.

Contingency: 22.5% (FY09), 30% (FY10), 37.5% (FY11).

No provisions for magnet failures, retests, etc. beyond contingency.

Assumes "special construction" reduced OH as in LHC (ok for TPC > $25M).

Minor updates still being made, rigorous internal check to come.

→ ~ $14.7M inc. contingency:

$0.6M (FY09), $3.3M (FY10), $5.4M (FY11), $5.4M (FY12)

Conclusions, Observations

- Easy start to production
- Plan developed demonstrates satisfaction of CERN delivery requirements
- Some technical issues need to be addressed
- Small schedule contingency – need early start of some activities if possible to provide additional cushion
- Very high probability of success (12 units operating in RHIC for ~ 9 years)